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OPTIMISATION OF GRINDING AND FLOTATION PARAMETERS; PILOT-PLANT TREATMENT OF QUEBEC TALC ORE

P.R.A. Andrews & J.P. Rouleau
Mineral Processing Laboratory

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OPTIMISATION OF GRINDING AND FLOTATION PARAMETERS; PILOT-PLANT TREATMENT OF QUEBEC TALC ORE FROM QUEBEC.

by

P.R.A. Andrews* & J.P. Rouleau**

ABSTRACT

Talc ore previously dry ground to approximately 85% -44µm was beneficiated in an 11.4 kg/h pilot-plant flotation circuit. A concentrate of 96% talc (necessary for paper-grade talc) was obtained at a recovery of 71%. Multiple-stage cleaning increased the grade to 97.2% talc but only at a recovery of 57.9%. Flotation of freshly ground ore, hammer mill product, at approximately 59.5% -44 µm, at a feed rate of 18.6 kg/h, produced a grade of 96% talc with a recovery of 74%.

The similarity in the grade/recovery relationships between pre-ground and fresh-ground ore indicates that it is not necessary to grind to approximately 85% -44 µm to achieve comparable selectivity. A grind of 59.5% -44 µm corresponds to 100% - 300 µm.

Flotation retention times obtained with fresh ground ore indicate a combined rougher/scavenger flotation time of 33 min and a cleaner flotation time of 15 min, for the first and second cleaners. When these figures are compared to the calculated retention times based on the earlier plant study[1], it is apparent that additional flotation cell capacity would be needed should the plant be expanded.

The iron oxide content was reduced by oxidative pressure leaching to 1.29% Fe_2O_3. This result was only achieved, however, by grinding a high grade talc concentrate to 2 µm in a laboratory jet mill. Further reduction could only be obtained at the expense of leaching talc; consequently, it is not practical to produce cosmetic-grade talc.

Keywords: Talc ore, grinding, flotation, multiple cleaning, iron oxide reduction, leaching, pilot-plant, retention times.

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* Minerals Engineer Industrial Minerals Section and **Technician, Metallic Mineral Section, Mineral Processing Laboratory, Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, Ottawa.

OPTIMISATION DES PARAMÈTRES DE BROYAGE ET DE FLOTTATION; TRAITEMENT EN USINE-PILOTE DU MINERAI DE TALC DU QUÉBEC

par

P.R.A. Andrews* et J.P. Rouleau**

RÉSUMÉ

Du minerai de talc, broyé à sec au préalable à -44µm dans une proportion de 85 % environ, a été enrichi dans un circuit de flottation d'une usine-pilote de 11,4 kg. Un concentré de talc pur à 96 % (nécessaire pour fabriquer du talc de qualité papier) a été produit à un taux de récupération de 71 %.

L'épuration en plusieurs étapes a porté la teneur à 97,2 % de talc, mais le taux de récupération a chuté à 57,9 %. Le flottation de minerai fraîchement broyé aux marteaux (environ 59,5 % de passé -44µm), à un débit d'alimentation de 18,6 kg/h, a produit du talc pur à 96 % à un taux de récupération de 74 %.

La similarité des relations teneur/taux de récupération entre les minerais pré-broyé et fraîchement broyé indique qu'il n'est pas nécessaire de broyer à -44µm dans une proportion de 85 % environ pour obtenir une sélectivité comparable. Un minerai broyé à 59,5 % à -44µm correspond à un minerai broyé à 100 % à -300 µm.

Pour la flottation du minerai fraîchement broyé, les temps de séjour sont: temps combiné de dégrossissage/épuisement de 33 min et temps de relavage de 15 min pour les première et deuxième cellules. Lorsque ces temps de séjour sont comparés à ceux calculés dans l'étude en usine antérieure (1), il appert que la capacité des cellules de flottation devait être augmentée advenant que l'usine soit agrandie.

La teneur en oxyde de fer a été réduite à 1,29 % Fe_2O_3 par lixiviation oxydative sous pression, dans la mesure où du concentré riche en talc était réduit à 2µm dans un broyeur à jet de laboratoire. Une réduction plus poussée nécessiterait la lixiviation du talc; par conséquent, il n'est pas pratique de produire du talc de qualité produit de beauté.

Mots clés: Minerai de talc, broyage, flottation, relavage en plusieurs étapes, réduction de l'oxyde de fer, lixiviation, usine-pilote, temps de séjour.

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* Ingénieur-minéralurgiste, Section des minéraux industriels, et

** technicien, Section des minéraux métalliques, Laboratoire de traitement des minéraux, Centre canadien de technologie des minéraux et de l'énergie, Énergie, Mines et Ressources Canada, Ottawa.

INTRODUCTION

In a previous study[2] concerning the laboratory scale evaluation of talc ore from Bakertalc, Highwater, Quebec, several recommendations were made concerning the optimisation of grinding and flotation parameters. It was demonstrated that the fine grind of approximately 85% -44 µm at present employed for feed to flotation was unnecessarily fine for complete liberation of minerals. By grinding at a slightly coarser size, consistent with liberation (100% -210 µm), a substantial reduction in power consumption would be achieved.

With respect to the planned expansion at Bakertalc, it is necessary to accurately establish flotation retention times so that necessary flotation cell capacity can be planned. Each of these paramaters have been addressed on a pilot-plant scale in this present CANMET study.

SAMPLE DESCRIPTION

Five tonnes of pre-dry ground, approximately 85% -44 µm, Raymond roller mill product (flotation feed) was delivered to the Industrial Minerals Laboratory in February 1986. A further five tonnes of -20 mm hammer mill discharge product was delivered in July 1986 (unground flotation feed).

PROCESSING PRE-GROUND ORE

Flotation

The pre-dry ground ore was used to establish the basic flotation parameters: feed rate, pulp density, rougher and cleaner collector concentration, number of cells for roughing and cleaning, number of cleaning stages and flotation retention time.

The basic circuit employed was a rougher-cleaner configuration with recirculation of cleaner tailings to the feed of the previous stage. A standard size 8.5 L cell was used throughout for both roughing and cleaning and Dowfroth 250 used as frother-collector at natural pH. Initially a feed rate of 44 kg/h was used with a feed density of 30% solids and two stages of cleaning. The collector concentration was steadily increased throughout the

test series (Tests 1 to 3) from zero in Test 1 to 47 g/t in Test 3. In Test 3 the feed rate was decreased to 20 kg/h and the number of cleaning stages increased to three. The test procedure involved running the circuit for 5 h to allow sufficient time for equilibrium. Between the fifth and sixth hour each feed, concentrate and tailing product was sampled for 30 sec at 20 min intervals. Each product was weighed both wet and dry for calculation of pulp density, pulp volume and flotation retention time. In addition, each product was analysed for talc* and Fe_2O_3.

In the second test series (Tests 4 to 9) the feed rate was decreased to 11.4 kg/h and the flotation cell capacity increased (see Fig. 1.):

Rougher	6 cells
Cleaner No 1	3 cells
Cleaner No 2	2 cells
Cleaner No 3	1 cell

The pulp density in Test 4 and 5 was maintained at 30% solids but the pulp density in Test 6 was decreased to 20% solids. Different levels of collector concentration were tested, the range being between 45 and 106 g/t. In Tests 7 to 9 a scavenger collector addition of 8 g/t was added to the feed of No 4 rougher cell. Simultaneously, the cleaner tailings No 1 product was redirected from the head of the rougher circuit to the feed of No 4 rougher cell. Each test was run for 5 h before sampling using the same sampling and pulp density calculation procedure, as was used in Tests 1 to 3. A summary of flotation parameter data is reported in Table 1 and detailed product balances are reported in Table 2.

The final concentrates from each run were stored, mixed and later re-run through the circuit to ascertain whether multiple re-cleaning would increase the grade of talc and reduce the iron oxide content. Two tests were conducted using 20 kg/h feed rate, 30% solids pulp density and sufficient collector added to maintain flotation; results are reported in Table 3.

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* Talc is a hydrated magnesium silicate and as such cannot be analysed in the conventional manner. Since talc is virtually the only insoluble mineral present in any appreciable quantity in the ore, the acid insoluble analysis (% insol.) will be approximately equal to the % talc content.

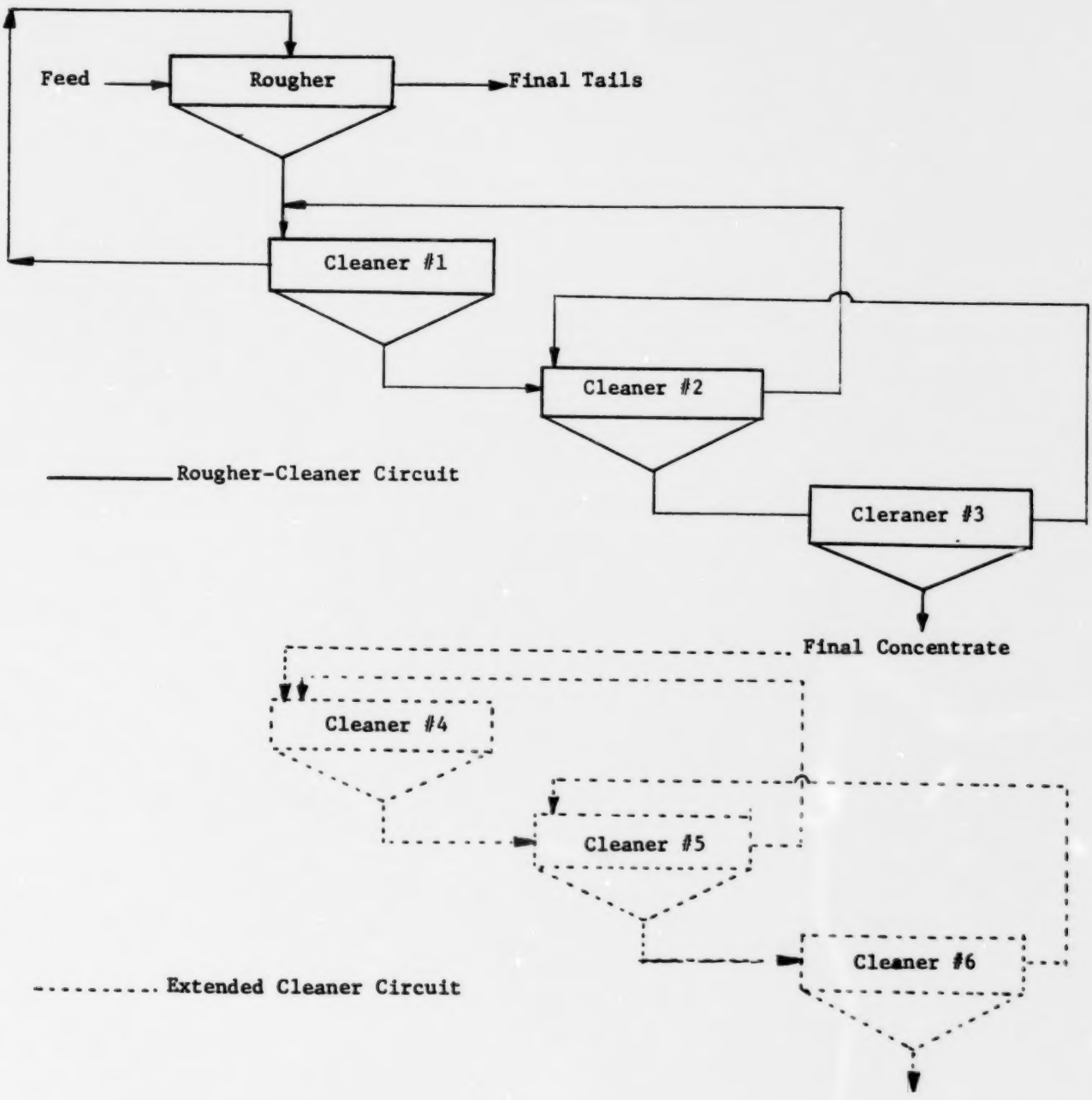

Fig. 1 - Rougher-cleaner and extended cleaner circuits for pre-ground ore

Spiral Concentration

Two tests were conducted using a No 7 Reichert spiral to separate pyrrhotite from talc. A 50 L conditioner was used as feed to the spiral and all spiral products discharged into a 40 mm Sala pump, which recirculated feed to the conditioner.

Talc ore was fed to the conditioner at the required pulp density. The conditioner discharge line was opened and feed passed down the spiral. When the system was in equilibrium, timed samples were taken simultaneously of the concentrate, middlings and tailings products. Samples were dried and prepared for chemical analysis; results are reported in Table 4.

Magnetic Separation

The removal of magnetic minerals was assessed by wet high intensity magnetic separation using both the Jones and Sala separators. When using the Jones separator, a 25 kg sample of talc ore was pre-mixed in a conditioner and fed to the rotating carousel. A current of 5A and the plates with the smallest grooves were used; the duration of the test was 30 min. All products were dried and prepared for chemical analysis; results are reported in Table 5. When using the Sala separator, 100g portions of feed were used. Several tests were conducted using different magnetic intensities and feed rates; results are reported in Table 6.

Atmospheric Acid Leaching

Leaching was initially conducted on pre-ground feed ore which proved impractical because the presence of carbonaceous material resulted in excessive frothing loss of talc. The evolution of CO_2, if vigorous enough, can result in boil-over and loss of entrained talc in the froth. Subsequent leaching was conducted on talc flotation concentrates which contained only minimum quantities of carbonaceous material. Agitation level was increased for better gas dispersion and autoclave slurries were vigorously mixed prior to autoclave conditions.

A series of six leach tests were conducted, the operating variables of which are reported in Table 7 and the metal extraction values in Table 8. Since one of the sources of iron is pyrite, and bacteria are known to dissolve FeS_2, a bacteria leach at pH 1.5 (Test 1) in H_2SO_4 media was performed. Tests 2 & 3 were performed using HCL with a reducing agent; sodium dithionite ($Na_2S_2O_4$) in Test 2 and sodium bisulphite ($NaHSO_3$) in Test 3. Tests 4 & 5 were performed using H_2SO_4 with sodium bisulphite at two levels of concentration.

Oxidative Pressure Leaching

Three tests were performed using H_2SO_4 at elevated pressures, the operating variables of which are reported in Table 7 and the metal extraction values in Table 8. In Test 6 an atmospheric pre-leach at 95°C was followed by an oxidative pressure leach, whereas Test 7 involved only an autoclave oxidative pressure leach. The conditions for Test 8 were a finer size and altered surface chemistry. Feed material for Test 8 was ground in a laboratory jet mill to <2 µm, and leaching was conducted in the presence of a surfactant. Surfactants have been shown to improve the leaching rates of other refractory minerals[3].

PROCESSING HAMMER MILL PRODUCT

Crushing

Minus 20 mm hammer mill discharge product was stage crushed to 3.4 mm. Size analysis indicated that 75.8% was +210 µm and approximately 10% was -44 µm.

Grinding

Several preliminary trial runs were conducted in a 0.45 m x 0.30 m ball mill to establish a grind of 100% -210 µm, without production of excessive -44 µm material. The grinding parameters established for these conditions were a 70 kg charge of 25 mm, 20 mm and 12.5 mm chromium-nickel alloy balls as grinding media; 18.2 kg/h feed rate; and 55 to 60% solids ball mill

discharge pulp density. The ball mill discharge was pumped to a 300 µm (50 mesh) Sweco screen. The screen oversize was re-circulated to the ball mill feed; the screen undersize was the flotation feed.

Flotation

The Sweco screen undersize, after dilution to 20% solids, was pumped to the flotation feed conditioner where collector was added. The flotation circuit (Fig. 2) was changed from the rougher-cleaner configuration of Fig. 1 to include a cleaner-scavenger stage. After rougher flotation, the rougher concentrate was cleaned in the normal manner with cleaner tails #1 being scavenged, instead of re-circulation of cleaner tails #1 "as is" back to the head of the rougher circuit. By introducing a scavenger stage, a high-grade scavenger concentrate was re-circulated back to the feed of cleaner #1 circuit, and an intermediate grade scavenger tail returned to the head of the rougher circuit. Prior to the introduction of the scavenger stage, cleaner tail #1 was re-circulated to the middle of the rougher circuit which increased the final tail analysis. By treating cleaner tail #1 separately the final tail analysis was reduced.

Four test runs were conducted with Dowfroth 250 collector at concentrations between 33.1 and 61.5 g/t. Three test runs with MIBC collector at concentrations between 47.3 and 71.0 g/t, and three test runs with Aerofroth 70 collector at concentrations between 52.0 and 71.0 g/t, also were conducted. In each test run an additional quantity of collector was added to the scavenger, which for the Dowfroth 250 test runs was 4.7 g/t. For the later test runs using MIBC and Aerofroth 70, the collector concentration was increased in the scavenger.

Each test was run for 5 h before sampling and the same sampling procedure was used as in the previous runs with pre-ground ore. Individual products were weighed wet and dry for calculation of pulp density, pulp volume and flotation retention time. A summary of grinding and flotation parameter data is reported in Table 9 and detailed product balances in Table 10.

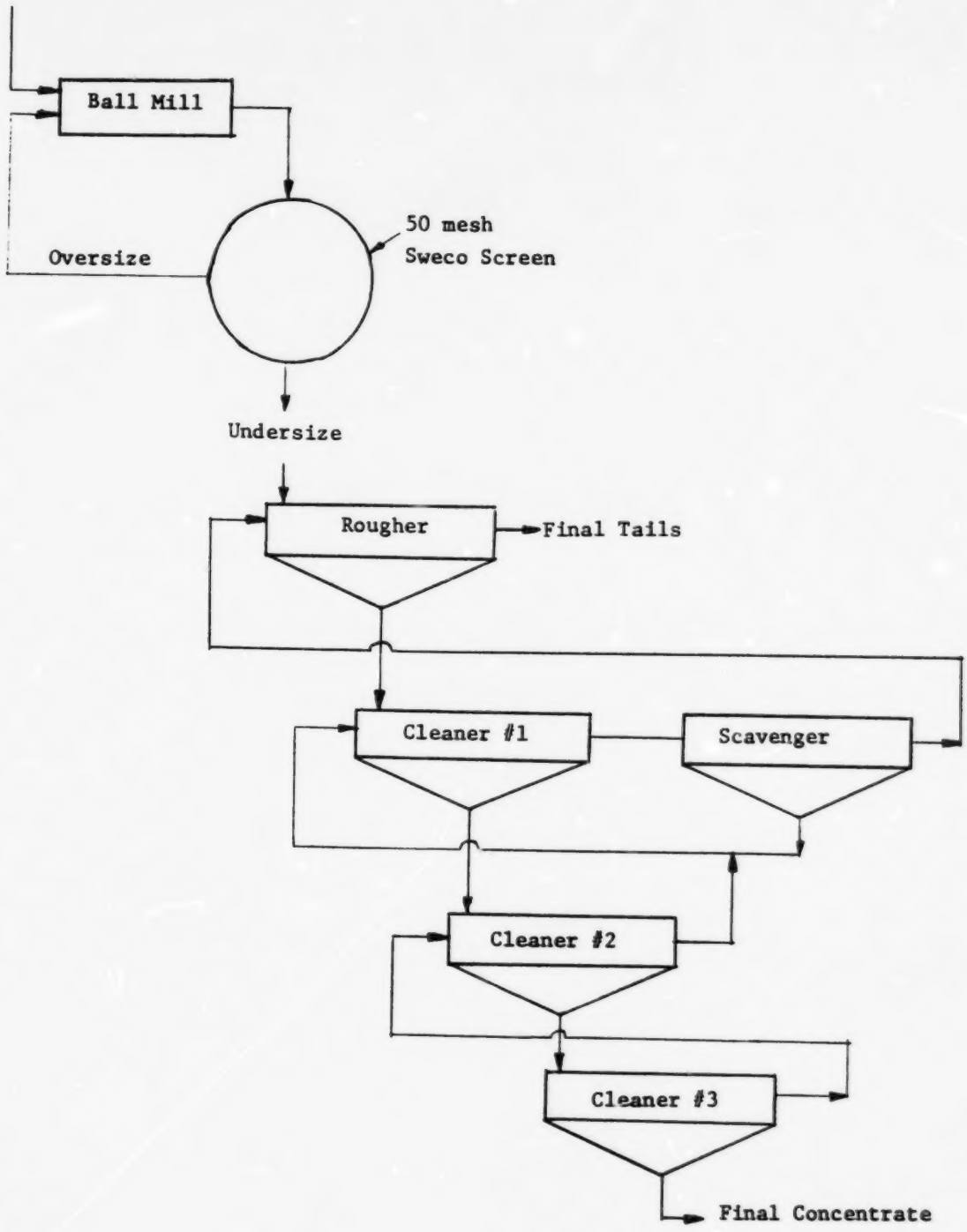

Fig. 2 - Grinding-flotation circuit for hammer mill product ore

Magnetic Separation

The removal of magnetic minerals was assessed using the Sala high intensity wet magnetic separator. A 100 g portion of flotation feed was fed at a rate of 144 mm/sec using a field strength of 13.8 k gauss; the results are reported in Table 11.

RESULTS: PRE-GROUND ORE

Flotation Parameters

The purpose of Tests 1 to 3 was to establish feed rate, collector concentration and number of cleaning stages etc., so that no serious effort was directed towards optimising grade and recovery. In Test 4, a basic circuit was established (Fig. 1) which was used for all remaining testwork (Tests 4 to 9).

In Test 4, 49 g/t of collector recovered 78.3% of the talc at a grade of 95.54%. By increasing the collector concentration to 91 g/t in Test 5, while the recovery was increased to 83.7%, the grade decreased to 93.57%. The increased collector concentration also resulted in an increase of the iron oxide distribution from 22.9% in Test 4, to 27.0% in Test 5.

In Test 6, the pulp density was reduced to 20% solids. The reason for the reduction from 30% to 20% solids was to increase the flow characteristics of froth concentrates; the collector concentration was decreased to 45 g/t. As with Tests 1 to 3, Test 6 was an exploratory test rather than a test in which optimum grade and recovery were achieved. A concentrate of 94.1% talc at 76.0% recovery was, however, a fair result.

In Tests 7 to 9, the effect of adding 8 g/t collector in the scavenger circuit and the effect of increasing collector concentration in the roughers were investigated. The best results were obtained in Test 7 where a rougher collector concentration of 45 g/t recovered 75.3% of the talc for a grade of 95.89%. An increase in rougher collector concentration to 76 g/t in Test 8 resulted in an increase of concentrate recovery to 82.0% but at a lower grade of 92.66%. Similarly in Test 9, an increase in the rougher collector concentration to 106 g/t did not improve either grade or recovery. As would be expected the iron oxide distribution increased from 20.1% in Test 7 to 28.3% in Test 8.

Flotation - Extended Cleaning

Final concentrate from Tests 1 to 9 were collected and used for two multiple recleaning tests. Three additional stages were added for a total of six cleaning stages (Fig. 1). The results reported in Table 3 indicate that the additional cleaning increased the grade of talc from 95.4% to 97.2%; the final recovery decreased from 75.0% to 57.9%. Surprisingly,the iron oxide analysis was only reduced from 3.54% to 3.36% Fe_2O_3, representing 15.4% of the total iron oxide distribution.

Flotation - Retention Times

Retention times were calculated for each test; a comparison of rougher and cleaner retention times for Test 7 with the theoretically required retention times[3] is shown as follows:

Flotation stage	Test #7 (min)	Theoretical time results (min)
Rougher	24.3	20
Cleaner #1	10.6	12
Cleaner #2	9.2	12
Cleaner #3	9.7	12

The retention times for Test 7 indicate that there was sufficient rougher flotation time, but that cleaner flotation times were approximately 20% less than the theoretically calculated values. The measured values are probably sufficient since the grade-recovery curve (Fig. 3) for pilot-plant flotation of pre-ground ore indicates an even better performance than the curve for laboratory-based results.

Spiral Concentration

Neither of the two tests conducted significantly concentrated the heavy oxide minerals. Furthermore, excessive amounts of talc were lost with the heavy mineral fraction (concentrate). Better results would probably be obtained with coarser-sized head material.

Magnetic Separation

A test conducted using the Jones wet high intensity separator rejected 57.8% of the iron oxide minerals for a talc loss of 27.4%. An improvement in iron oxide rejection and reduction in talc loss was obtained using the Sala high intensity magnetic separator. By varying the feed rate and field strength intensity, 65.3% of the iron oxide minerals were rejected for a talc loss of only 11.6%. This result was obtained with a feed rate of 341 mm/sec and a field strength of 13.8 k gauss. It is possible that this result could be improved by further investigating feed rate and field strength.

Atmospheric Acid Leaching

Talc concentrate samples were leached employing a variety of conditions. None of the leach tests, however, produced a cosmetic grade talc (<0.7% Fe_2O_3). The leached residues analysed from 3.48% Fe_2O_3 to 3.18% Fe_2O_3, which corresponded to extractions of from 2.0%) to 25.7%.

In Test 1, only 2% extraction was obtained after 8 days, at which time the Fe^{3+} concentration decreased and the test was terminated after 10 days. In Tests 2 and 3, the extraction rates were improved slightly. Employing a 6 h leach at 95°C, a 13.4% extraction of Fe_2O_3 was obtained in Test 2 using the Hcl - $Na_2S_2O_4$ combination; in Test 3, an 18.6% extraction of Fe_2O_3 was obtained using the HCl - $NaHSO_3$ system. Both reducing agent/HCl leach systems, however, leach MgO (from talc) as well as Fe_2O_3.

By increasing the $NaHSO_3$ concentration from 10 g/kg (Test 4) to 20 g/kg (Test 5), the extraction of Fe_2O_3 increased from 16.6% to 25.7%. Simultaneously, the MgO increased from 12.0% in Test 4 to 19.6% in Test 5. In both tests the Fe_2O_3 and MgO extraction curves (see Fig. 4) show a linear dependence with time. The effect of increasing the $NaHSO_3$ addition from 10 to 20 g/kg of concentrate is to increase the leaching rates of both Fe_2O_3 and MgO. Assuming that 20 g $NaHSO_3$ has sufficient capacity to maintain linear leaching of all Fe contaminates, and assuming further a 30% weight loss, a cosmetic grade product (Fe_2O_3 <0.7%) could be produced after 29.5 h residence time. After this time, however, the MgO extraction would be 80% which corresponds to a similar percent loss of talc.

Oxidative Pressure Leaching

The extraction values for Tests 6 and 7 suggests that an atmospheric pre-leach at 95°C with 177 kg/m³ H_2SO_4, followed by an oxidative pressure leach at 110°C, 426 KPa O_2 pressure, (using the pre-lixiviant H_2SO_4 pregnant) is more effective for Fe_2O_3 extraction than autoclave leaching alone. A two-stage leach extracted 27.3% Fe_2O_3 (Test 6) and only 20.3% $Fe_2)_3$ was leached under autoclave leaching (Test 7). These results suggest that Fe_2O_3 extraction is not strongly dependent on temperature and oxygen partial pressure. Equivalent or better Fe_2O_3 extraction can be obtained at atmospheric pressure using more concentrated H_2SO_4 (618 kg/m³) lixiviants and $NaHSO_3$ addition (Test 5, 25.7% Fe_2O_3 extraction).

In Test 8 approximately 50% Fe_2O_3 extraction was obtained and the improved Fe_2O_3 extraction (compared to Tests 6 and 7) may be attributed to the surfadifferent ce chemistry. The combination of a surfactant and finer feed (<2 µm) have improved the leach kinetics of the Fe bearing minerals. After 2 and 4h retention time, Fe_2O_3 extractions of 42.5 and 49.8% were obtained. Finer grinding has possibly liberated more Fe_2O_3 and the surfactant has possibly improved the leach kinetics. The final residue of Test 8 analysed 1.29% Fe_2O_3.

RESULTS: HAMMER MILL PRODUCT

Flotation Using Dowfroth 250

Four tests were conducted (Tests 10 to 13) using increasing concentrations of Dowfroth 250 in the rougher circuit, from 33.1 g/t in Test 10 to 61.5 g/t in Test 13. A constant concentration of 4.7 g/t of collector was added to the scavenger circuit in each test. A summary of the grade and recovery of talc concentrates for each test is as follows:

Test No	Grade %	Recovery %
10	97.03	68.8
11	96.94	75.9
12	96.51	70.8
13	93.55	75.6

As might be expected increasing the concentration of collector results in increased recovery, but also reduced grade. The best grade/recovery combination, Test 10, was in fact achieved with the least amount of collector, 33.1 g/t, and the coarsest grind, 51.5% - 44 µm. While in Tests 10 and 11 the grind was held at approximately 50% - 44 µm, difficulty was experienced in Tests 12 and 13 in maintaining a coarse grind. The variation in grind size (Table 9), however, did not noticeably affect the grade/recovery trend of Tests 10 to 13.

The calculated retention times for each stage of flotation in each of the four tests varied considerably. This was due to slight inaccuracies in chemical analysis and variations in product percent weights and product pulp densities between tests. Average retention times for Tests 10 to 13 are as follows:

Flotation stage	Average retention time (min)	Range of retention times (min)
Rougher	16.2	13.8 to 20.7
Scavenger	16.6	11.3 to 28.3
Cleaner #1	15.3	11.4 to 19.1
Cleaner #2	14.7	8.4 to 19.9
Cleaner #3	23.4	21.4 to 25.9

These average values suggest that rougher-scavenger flotation requires 32.8 min, which is the amount predicted by laboratory testwork (32 min). Each of the cleaner stages required slightly more cleaning time than predicted by laboratory testwork (12 min for each stage). The high value for Cleaner #3 is not representative since excess flotation cell capacity was used; a result similar to Cleaner #1 or #2 should be expected.

Flotation Using MIBC

Three tests were conducted (Test 14 to 16) using increasing concentrations of MIBC (methyl iso-butyl carbinol) in the rougher circuit, from 47.3 g/t in Test 14, to 71.0 g/t in Test 16. Collector added in the scavenger circuit also increased from 4.7 g/t in Test 14, to 9.5 g/t in

Test 16. A summary of the grade and recovery of talc concentrates for each test is as follows:

Test No	Grade %	Recovery %
14	96.59	52.4
15	94.77	71.6
16	92.53	80.1

As might be expected increasing the concentration of collector results in increased recovery, but also reduced grade. A performance comparison between MIBC and Dowfroth 2.50 at a constant collector concentration of 61.5 g/t, Test 13 (Dowfroth 250) and Test 15 (MIBC), demonstrates similarity in performance. The grind for Tests 14 to 16 was maintained between 53.6 and 59.1% - 44 µm.

The calculated retention times for each stage of flotation in each of the three tests varied considerably for reasons previously noted. Average retention times for Tests 14 to 16 are as follows:

Flotation stage	Average retention time (min)	Range of retention times (min)
Rougher	14.5	12.7 to 15.4
Scavenger	9.4	7.1 to 11.3
Cleaner #1	12.6	9.4 to 17.2
Cleaner #2	10.5	7.1 to 13.4
Cleaner #3	17.5	14.4 to 20.6

Flotation Using Aerofroth 70

Three tests were conducted (Tests 17 to 19) using increasing concentrations of Aerofroth 70 (six-carbon, branch-chain alcohol) in the rougher circuit, from 52.0 g/t in Test 17 to 71.0 g/t in Test 19. Collector addition in the scavenger circuit was maintained at 7.1 g/t for Tests 17 and 18, and increased to 9.5 g/t in Test 19. A summary of the grade and recovery of talc concentrates for each test is as follows:

Test No	Grade %	Recovery %
17	96.41	78.2
18	90.97	81.9
19	96.15	81.0

By increasing the collector concentration, the familiar grade/recovery relationship was produced, that is, increased recovery but reduced grade. The performance of Test 19, however, produced both a high grade and a high recovery. A performance comparison between Aerofroth 70, Dowfroth 250 and MIBC, at a constant collector concentration of 61.5 g/t is shown by comparing Test 18 (Aerofroth 70) with Test 13 (Dowfroth 250) and Test 15 (MIBC). The performance of each collector is similar; the lower grade of Test 18 is offset by a higher recovery. The grind for Tests 17 to 19 was maintained between 55.9% and 58.9% - 44 µm.

The calculated retention times for each stage of flotation in each of the three tests varied considerably for reasons previously noted. Average retention times for Tests 17 to 19 are as follows:

Flotation stage	Average retention time (min)	Range of retention times (min)
Rougher	12.5	12.0 to 12.9
Scavenger	8.5	6.3 to 9.6
Cleaner #1	12.4	11.9 to 12.9
Cleaner #2	8.7	7.3 to 11.0
Cleaner #3	16.1	13.7 to 19.0

Magnetic Separation

When employing a grind of 68.3% - 44 µm, 73.4% of the iron oxide minerals were removed for a talc loss of 30.8%. This result indicates a greater loss of talc than Test 5 results (see Table 6), where pre-ground ore sizing approximately 85% - 44 µm was used. A rejection of 65.3% of the iron oxide minerals was obtained for a talc loss of 11.6%.

COMMENTS

The rougher flotation retention time of 25 min for pre-ground ore was obtained at a feed rate of 11.4 kg/h. Since the grade and recovery values obtained were comparable to actual plant results [1], the feed rate was considered representative. Subsequent beneficiation of freshly ground ore, however, was conducted at a higher feed rate of 18.6 kg/h. The aim in conducting testwork at almost double the initial feed rate was to ascertain whether additional cell capacity would be required, and how the retention times would be affected. This was considered the best assessment of what could be expected when the expansion of the flotation circuit is implemented at Bakertalc. Comparable grade and recovery values to plant results could only be obtained by increasing the rougher flotation cell capacity (scavenger circuit) by 50%, which resulted in a combined rougher-scavenger flotation retention time of 33 min. It was also necessary to increase the second cleaner cell capacity by 50% in order to maintain a retention time of 15 min. The increase by 200% in the third cleaner cell capacity was excessive, and resulted in the high retention time of 23 min. The reason for the use of excess cell capacity for the third cleaner was unavailability of small scale cells so that larger cells had to be used.

While these figures are considered to be reasonable estimates, they should not be used as absolute values; however, they do suggest that for increased throughput additional cell capacity would be required.

CONCLUSIONS

Pre-Ground Ore

1. The grade/recovery curve for pre-ground approximately 85% -44 μm ore in Fig. 3 indicates that the pilot-plant circuit was operating efficiently; a grade of 96% talc can be obtained with a recovery of 71%.

2. Extended cleaning increases the final grade up to 97.2% talc but only at a recovery of 57.9%. The reduction in iron oxide content is from 3.54% to 3.36% Fe_2O_3.

3. Rougher flotation based on a feed rate of 11.4 kg/h requires a flotation time of 25 min, and each stage of cleaning requires 10 min flotation time.

4. Magnetic separation using the Sala HGMS removed 65.3% of the iron oxide minerals with a talc loss of only 11.6%.

5. Atmospheric leaching did not produce cosmetic grade talc; H_2SO_4, supplemented with $NaHSO_3$ was the most effective atmospheric leach condition. Fe_2O_3 and MgO extractions of 25.7 and 19.6% wt respectively were obtained and the final residue analysed 3.18% Fe_2O_3.

6. Oxidative pressure leaching did not produce cosmetic grade talc. A 50% wt Fe_2O_3 extraction could be obtained provided that -2 µm feed and a surfactant were used. The final residue analysed 1.29% Fe_2O_3.

Hammer Mill Product

1. The grade/recovery curve for talc ore ground to approximately 59.5% -44 µm, in Fig. 3 indicates that the pilot-plant circuit was operating efficiently; a grade of 96% talc can be obtained with a recovery of 74%.

2. At a constant concentration of 61.5 g/t the performance of Aerofroth 70, MIBC and Dowfroth 250 collectors was demonstrated to be equally selective and efficient.

3. Rougher flotation retention time is longer with Dowfroth 250 requiring 16.2 min; with MIBC 14.5 min is required and with Aerofroth 70, 12.5 min is required.

4. A similar trend was noted in each of the three stages of cleaning, Dowfroth 250 required more retention time than MIBC and Aerofroth 70 required the least retention time.

5. Magnetic separation using the Sala wet high intensity magnetic separator rejected 73.4% of the iron oxide minerals for a talc loss of 30.8%.

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REFERENCES

1. Andrews P.R.A. "Processing talc in Canada - a review of studies at CANMET"; Industrial Minerals; No 225; pp 63-69; June 1986.

2. Andrews P.R.A. "A laboratory study of the flotation circuit at Bakertalc Inc., Highwater, Quebec"; CIM Bulletin; Vol 78; No 884; pp 75-78; December 1985.

3. Lucas, B.H. and Shimano, D.H. "Improvement in Metal Extractions in a $FeCl_3$ Leach by the Addition of a Surfactant"; Division Report MRP/MSL 86-2(CF); CANMET, Energy, Mines and Resources; 1986.

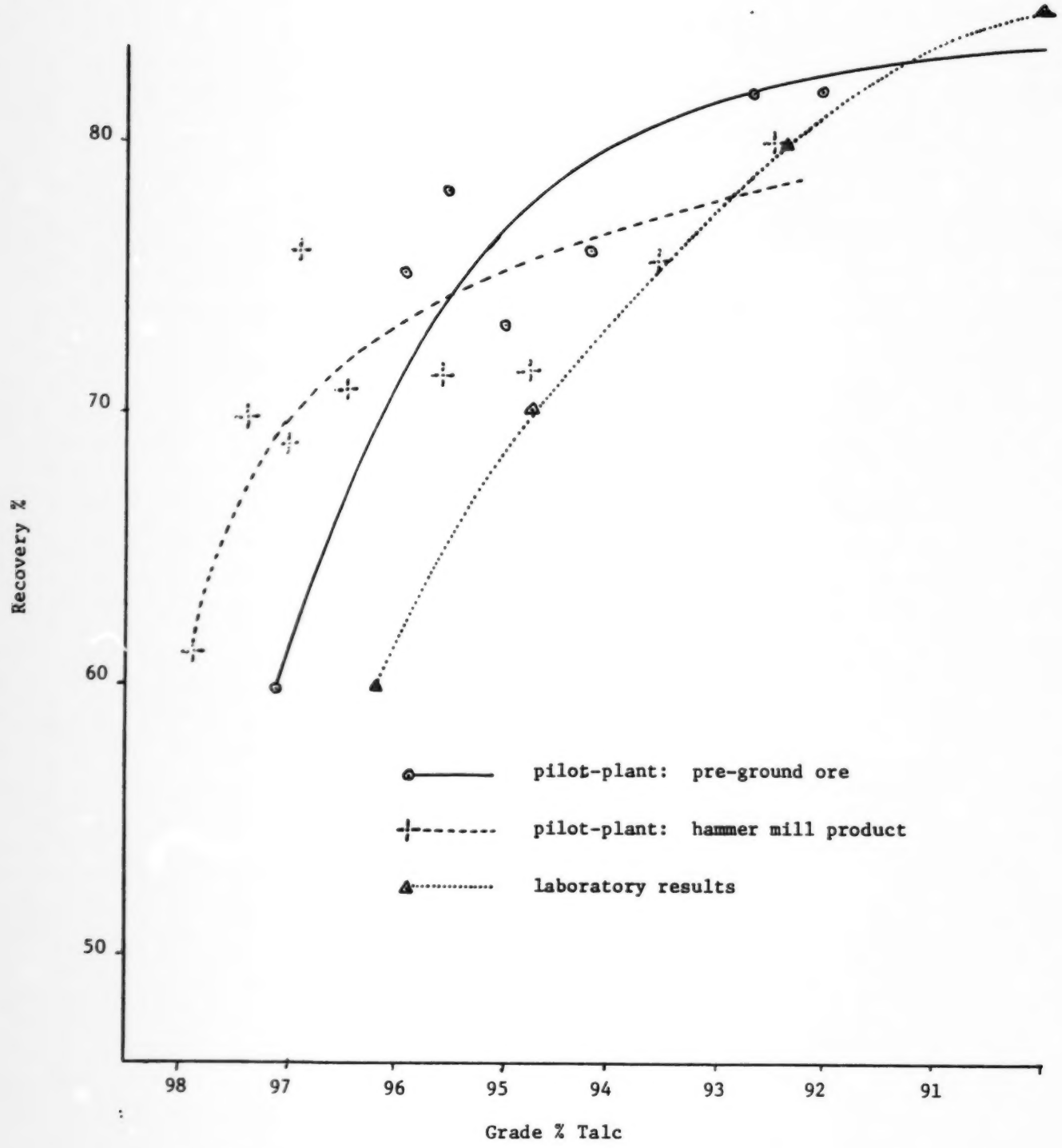

Fig. 3 - Relationship between grade and recovery of talc

Table 1 - Flotation parameter data: pre-ground ore

Test No	Flotation Stage	Feed Rate kg/h	Collector Concn. g/	No of Cells	Cell Volume L	Pulp Density % solids	Pulp Volume L	Retention Time min
1.	Feed	43.8	-	-	-	30.0	117.2	-
	Rougher	46.7	-	3	20.0	27.0	142.4	8.4
	Cleaner #1	11.0	-	2	17.0	18.5	52.6	19.4
	Cleaner #2	7.2	-	1	8.5	16.5	43.8	11.6
2.	Feed	44.5	20.0	-	-	30.0	119.0	-
	Rougher	48.0	-	3	20.0	26.6	149.2	8.1
	Cleaner #1	12.7	-	2	17.0	18.5	59.3	17.2
	Cleaner #2	9.1	-	1	8.5	16.5	49.0	10.4
3.	Feed	21.7	47.0	-	-	30.0	58.0	-
	Rougher	26.0	-	3	25.5	23.1	95.4	16.0
	Cleaner #1	12.6	-	2	17.0	17.7	63.0	16.4
	Cleaner #2	8.9	-	1	8.5	15.6	51.2	10.0
	Cleaner #3	7.1	-	1	8.5	21.8	27.8	18.4
4.	Feed	11.4	49	-	-	30.0	30.5	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	30.0	30.5	50.2
	*Rougher + Cleaner Tails #1	9.9	-	3	25.5	13.1	68.7	22.3
	**(Rougher)	17.9	-	6	51.0	18.2	86.6	35.3
	Cleaner #1	14.3	-	3	25.5	17.8	71.1	21.5
	Cleaner #2	9.1	-	2	17.0	15.0	54.5	18.7
	Cleaner #3	7.0	-	1	8.5	21.8	27.5	18.6
5.	Feed	11.4	91	-	-	30.0	15.4	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	30.0	30.5	50.2
	Rougher + Cleaner Tails #1	11.0	-	3	25.5	12.8	78.4	19.5
	(Rougher)	19.0	-	6	51.0	17.5	81.2	31.8
	Cleaner #1	16.4	-	3	25.5	17.7	81.5	18.8
	Cleaner #2	9.9	-	2	17.0	15.2	58.5	17.4
	Cleaner #3	7.5	-	1	8.5	21.8	29.4	17.4

Table 1 Cont'd - Flotation parameter data: pre-ground ore

Test No	Flotation Stage	Feed Rate kg/h	Collector Concn. g/	No of Cells	Cell Volume L	Pulp Density %solids	Pulp Volume L	Retention Time min
6.	Feed	11.4	45	-	-	20.0	49.5	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	20.0	49.5	30.9
	Rougher + Cleaner Tails #1	7.7	-	3	25.5	5.4	127.0	12.0
	(Rougher)	15.6	-	6	51.0	11.2	129.9	23.6
	Cleaner #1	11.1	-	3	25.5	8.8	118.8	12.9
	Cleaner #2	8.3	-	2	17.0	9.3	83.7	12.2
	Cleaner #3	6.8	-	1	8.5	14.5	42.5	12.0
7.	Feed	11.4	45	-	-	20.0	49.5	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	20.0	49.5	30.9
	Rougher + Cleaner Tails #1	7.5	8	3	25.5	5.4	133.4	11.5
	(Rougher)	15.5	-	6	51.0	11.3	126.2	24.3
	Cleaner #1	11.6	-	3	25.5	7.6	144.0	10.6
	Cleaner #2	10.7	-	2	17.0	9.1	110.7	9.2
	Cleaner #3	8.4	-	1	8.5	14.5	52.6	9.7
8.	Feed	11.4	76	-	-	20.0	49.5	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	20.0	49.5	30.9
	Rougher + Cleaner Tails #1	8.7	8	3	25.5	5.4	156.6	9.8
	(Rougher)	16.7	-	6	51.0	10.4	149.4	20.5
	Cleaner #1	13.2	-	3	25.5	9.0	137.7	11.1
	Cleaner #2	9.7	-	2	17.0	9.3	98.0	10.4
	Cleaner #3	8.0	-	1	8.5	14.5	50.1	10.2
9.	Feed	11.4	106	-	-	20.0	49.5	-
	Rougher (Cells 1 to 3)	11.4	-	3	25.5	20.0	49.5	30.9
	Rougher + Cleaner Tails #1	8.9	8	3	25.5	5.4	159.8	9.6
	(Rougher)	16.8	-	6	51.0	10.3	152.6	20.1
	Cleaner #1	12.9	-	3	25.5	9.4	128.6	11.9
	Cleaner #2	9.2	-	2	17.0	9.3	93.0	11.0
	Cleaner #3	7.8	-	1	8.5	14.5	48.7	10.5

* A feed value of 30% weight, based on laboratory testwork is assumed for the feed to the No 4 rougher cell; the pulp density is assumed to be the same as the final rougher tails pulp density.

** (Rougher) - has been calculated based on the No 1 cleaner tailings being added at the head of the rougher circuit, which would be the case on a larger scale. It was not practical on the scale of this investigation to add the No 1 cleaner tailings at the head of the rougher circuit.

Table 2 - Product balances: pre-ground ore

Test No 1 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Recleaner conc	15.9	89.6	4.01	23.0	-
Recleaner tails	2.6	71.5	7.23	3.0	-
Recleaner feed	18.5	-	-	-	-
(Cleaner conc)	18.5	(87.1)	-	26.0	-
Cleaner conc	18.5	87.1	4.33	26.0	-
Cleaner tails	6.7	55.5	7.80	6.0	-
Cleaner feed	25.2	(78.7)	-	32.0	-
(Rougher conc + Recleaner tails)	25.2	-	-	-	-
Rougher conc	22.6	78.7	5.36	28.8	-
Rougher tails	84.1	56.9	7.97	77.2	-
Calculated feed (Feed + Cleaner tails)	106.7	(61.6)	-	106.0	-
Feed	100.0	62.0	7.26	100.0	-

Table 2 Cont'd - product balances: pre-ground ore

Test No 2 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Recleaner conc	17.7	89.6	4.03	25.4	-
Recleaner tails	2.8	71.7	6.18	3.2	-
Recleaner feed	20.5	-	-	-	
(Cleaner conc)	20.5	87.2	-	28.6	-
Cleaner conc	20.5	87.2	4.32	28.6	-
Cleaner tails	7.8	58.1	7.78	7.3	-
Cleaner feed	28.3	-	-	-	
(Rougher Conc + Recleaner tails)	28.3	(79.2)	-	35.9	-
Rougher conc	25.5	80.1	5.24	32.7	-
Rougher tails	82.3	56.5	7.95	74.4	-
Calculated feed (Feed + Cleaner tails)	107.8	(62.2)	-	107.3	-
Feed	100.0	62.5	6.19	100.0	-

Table 2 Cont'd - Product balances: pre-ground ore

Test No 3 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	29.3	95.59	3.04	44.9	17.2
Cleaner tails #3	3.3	88.19	3.87	4.7	-
Cleaner feed #3	32.6	94.84	-	49.5	-
Cleaner conc #2	32.6	94.84	3.17	49.5	-
Cleaner tails #2	8.5	83.63	4.36	11.4	-
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	41.1	92.52	-	60.9	-
Cleaner conc #1	37.7	93.15	3.46	56.2	-
Cleaner tails #1	20.0	65.54	6.37	21.0	-
Cleaner feed #1 (Rougher Conc + Cleaner tails #2)	57.7	83.58	-	77.2	-
Rougher conc	49.3	83.40	4.36	65.9	-
Rougher tails	70.7	48.70	8.29	55.1	82.8
Calculated feed (Feed + Cleaner tails #1)	120.0	-	-	121.0	-
Measured Feed	100.0	62.44	6.39	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 4 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	50.6	95.54	3.55	78.3	22.9
Cleaner tails #3	10.7	90.91	4.17	15.8	5.7
Cleaner feed #3	61.3	94.73	3.66	94.1	28.6
Cleaner conc #2	61.3	94.73	3.66	94.1	28.6
Cleaner tails #2	18.3	77.21	5.86	22.9	13.7
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	79.6	90.70	4.16	117.0	44.3
Cleaner conc #1	68.9	90.66	4.15	101.1	36.5
Cleaner tails #1	56.7	38.69	11.2	35.5	80.9
Cleaner feed #1 (Rougher conc + Cleaner tails #2)	125.6	67.19	7.34	136.6	117.4
Rougher conc	107.2	65.50	7.16	113.7	103.8
Rougher tails	49.5	27.22	12.9	21.8	77.1
Calculated feed (Feed + Cleaner tails #1)	156.7	53.41	9.06	135.5	180.9
Measured feed	100.0	61.76	7.85	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 5 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	55.9	93.57	3.76	83.7	27.0
Cleaner tails #3	9.7	87.54	4.55	13.6	5.7
Cleaner feed #3	65.6	92.68	3.88	97.3	32.7
Cleaner conc #2	65.6	92.68	3.88	97.3	32.7
Cleaner tails #2	21.3	67.36	7.18	23.0	19.6
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	86.9	86.47	4.68	120.3	52.3
Cleaner conc #1	77.2	86.40	4.70	106.7	46.6
Cleaner tails #1	66.4	32.17	11.7	34.2	99.3
Cleaner feed #1 (Rougher conc + Cleaner tails #2)	143.6	61.32	-	140.9	145.9
Rougher conc	122.3	60.26	7.88	117.9	123.6
Rougher tails	44.1	23.14	13.4	16.3	75.8
Calculated feed (Feed + Cleaner tails #1)	166.4	50.40	9.34	134.2	199.4
Measured feed	100.0	62.51	7.80	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 6 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	47.2	94.10	3.77	76.0	21.6
Cleaner tails #3	12.5	88.11	4.53	18.9	6.9
Cleaner feed #3	59.7	92.85	3.93	94.9	28.5
Cleaner conc #2	59.7	92.85	3.93	94.9	28.5
Cleaner tails #2	12.8	70.47	6.73	15.4	10.4
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	72.5	88.91	4.42	110.3	38.9
Cleaner conc #1	60.0	89.07	4.40	91.4	32.0
Cleaner tails #1	37.2	47.46	9.99	30.2	45.0
Cleaner feed #1 (Rougher conc + Cleaner tails #2)	97.2	73.11	6.54	121.6	77.0
Rougher conc	84.4	73.55	6.51	106.2	66.6
Rougher tails	52.8	26.57	12.26	24.0	78.4
Calculated feed (Feed + Cleaner tails #1)	137.2	55.46	8.72	130.2	145.0
Measured feed	100.0	58.44	8.25	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 7 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	46.3	95.89	3.56	75.3	20.1
Cleaner tails #3	27.6	92.03	4.06	43.1	13.7
Cleaner feed #3	73.9	94.45	3.75	118.4	33.8
Cleaner conc #2	73.9	94.45	3.75	118.4	33.8
Cleaner tails #2	19.7	80.88	5.43	27.0	13.1
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	93.6	91.54	4.10	145.4	46.9
Cleaner conc #1	66.0	91.34	4.12	102.3	33.2
Cleaner tails #1	35.5	57.14	8.49	34.4	36.8
Cleaner feed #1 (Rgh conc + Cleaner tails #2)	101.5	79.37	5.65	136.7	70.0
Rougher conc		79.03	5.70	109.7	56.9
Rougher tails	81.8 53.7	27.11	12.2	24.7	79.9
Calculated feed (Feed + Cleaner tails #1)	135.5	58.46	8.28	134.4	136.8
Measured feed	100.0	58.93	8.20	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 8 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	55.0	92.66	3.98	82.0	28.3
Cleaner tails #3	15.4	84.54	4.28	20.9	8.5
Cleaner feed #3	70.4	90.89	4.05	102.9	36.8
Cleaner conc #2	70.4	90.89	4.05	102.9	36.8
Cleaner tails #2	14.3	68.19	7.36	15.7	13.6
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	84.7	87.07	5.05	118.6	50.5
Cleaner conc #1	69.4	87.54	4.67	97.7	41.9
Cleaner tails #1	46.2	45.07	10.5	33.5	62.8
Cleaner feed #1 (Rougher conc + Cleaner tails #2)	115.6	70.57	7.00	131.2	104.7
Rougher conc	101.3	70.90	6.95	115.5	91.1
Rougher tails	44.9	24.82	12.34	17.9	71.7
Calculated feed (Feed + Cleaner tails #1)	146.2	56.77	8.61	133.4	162.8
Measured feed	100.0	62.18	7.73	100.0	100.0

Table 2 Cont'd - Product balances: pre-ground ore

Test No 9 Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Final concentrate	53.7	92.05	4.00	79.9	27.9
Cleaner tails #3	14.7	81.89	5.27	19.5	10.1
Cleaner feed #3	68.4	89.93	4.27	99.4	38.0
Cleaner conc #2	68.4	89.93	4.27	99.4	38.0
Cleaner tails #2	12.0	63.08	7.84	12.2	12.2
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	80.4	85.87	4.81	111.6	50.2
Cleaner conc #1	65.7	86.76	4.70	92.1	40.2
Cleaner tails #1	47.7	38.47	11.5	29.7	71.3
Cleaner feed #1 (Rougher conc + Cleaner tails #2)	113.3	66.52	-	121.8	111.5
Rougher conc	101.3	66.95	7.54	109.6	99.3
Rougher tails	46.3	26.91	12.0	20.1	72.1
Calculated feed (Feed + Cleaner tails #1)	147.6	54.32	8.93	129.7	171.3
Measured feed	100.0	61.88	7.69	100.0	100.0

Table 3 - Multiple recleaning tests

Recleaner Test 1	Relative	Actual	Pulp	Analysis %		Distribution		Distribution	
Products	Weight	Weight	Density			Relative %		Actual %	
	%	%	% solids	Insol	Fe_2O_3	Insol	Fe_2O_3	Insol	Fe_2O_3
Cleaner Conc #6	75.3	36.9	30.0	97.2	3.40	76.7	72.3	57.5	15.7
Cleaner Tails #6	113.0	55.4	25.2	96.2	3.44	114.0	109.8	85.5	23.8
Cleaner Feed #6	188.3	92.3	-	96.6	3.42	190.7	182.1	143.0	39.5
(Cleaner Conc #5)	188.3	92.3	-	96.6	3.42	190.7	182.1	143.0	39.5
Cleaner Conc #5	188.3	92.3	-	96.6	3.42	190.7	182.1	143.0	39.5
Cleaner Tails #5	31.4	15.4	20.1	96.6	3.68	31.1	32.6	23.3	7.1
Cleaner Feed #5	219.7	107.7	-	96.3	3.46	221.8	214.7	166.4	46.6
(Cleaner Conc #4 + Cleaner Tails #6)	219.7	107.7	-	96.3	3.46	221.8	214.7	166.4	46.6
Cleaner Conc #4	106.7	52.3	24.4	96.3	3.41	107.7	102.8	80.8	22.3
Cleaner Tails #4 (Final Tails)	24.7	12.1	14.5	89.9	4.26	23.3	29.8	17.5	6.5
Cleaner Feed #4 (Calculated Feed)	131.4	64.4	-	95.2	3.57	131.0	132.6	98.3	28.8
(Cleaner Conc #3 + Cleaner Tails #5)	131.4	64.4	-	95.2	3.57	131.0	132.6	98.3	28.8
Cleaner Conc #3 (Measured Feed)	100.0	49.0	30.2	95.4	3.54	100.0	100.0	75.0	21.7

Table 3 Cont'd - Multiple recleaning tests

Recleaner Test 2	Relative	Actual	Pulp	Analysis %		Distribution		Distribution	
Products	Weight	Weight	Density			Relative %		Actual %	
	%	%	% solids	Insol	Fe_2O_3	Insol	Fe_2O_3	Insol	Fe_2O_3
Cleaner Conc #6	75.6	37.0	28.1	97.1	3.36	77.2	70.8	57.9	15.4
Cleaner Tails #6	151.2	74.1	24.9	95.9	3.45	152.5	145.3	114.4	31.5
Cleaner Feed #6	226.8	111.1	25.9	96.3	3.42	229.7	216.1	172.3	46.9
(Cleaner Conc #5)	226.8	111.1	25.9	96.3	3.42	229.7	216.1	172.3	46.9
Cleaner Conc #5	226.8	111.1	25.9	96.3	3.42	229.7	216.1	172.3	46.9
Cleaner Tails #5	52.4	25.7	18.8	94.7	3.69	52.2	53.9	39.1	11.7
Cleaner Feed #5	279.2	136.8	-	96.0	3.47	281.9	270.0	211.4	58.6
(Cleaner Conc #4 + Cleaner Tails #6)	279.2	136.8	-	96.0	3.47	281.9	270.0	211.4	58.6
Cleaner Conc #4	128.0	62.7	24.2	96.0	3.49	129.2	124.4	96.9	27.0
Cleaner Tails #4 (Final Tails)	24.4	12.0	12.6	88.9	4.33	22.8	29.3	17.1	6.4
Cleaner Feed #4 (Calculated Feed)	152.4	74.7	-	94.9	3.62	152.0	153.7	114.0	33.4
(Cleaner Conc #3 + Cleaner Tails #5)	152.4	74.7	-	94.9	3.62	152.0	153.7	114.0	33.4
Cleaner Conc #3 (Measured Feed)	100.0	49.0	30.6	95.1	3.59	100.0	100.0	75.0	21.7

Table 4 - Spiral concentration test

Test No	Products	Weight %	Pulp Density %solids	Analysis %		Distribution %	
				Insol	Fe_2O_3	Insol	Fe_2O_3
1.	Concentrate	7.0	45	54.90	8.64	6.3	7.8
	Middlings	35.0		61.21	7.73	35.5	35.4
	Tailings	57.6		61.57	7.64	58.2	56.8
	Calculated head	100.0		60.98	7.74	100.0	100.0
2.	Concentrate	6.7	35	33.04	12.4	3.6	10.6
	Middlings	39.9*		62.93*	7.57	40.9	38.6
	Tailings	53.4		63.74	7.47	55.5	50.8
	Calculated head	100.0		61.36	7.84	100.0	100.0

* Estimated

Table 5 - Jones magnetic separation test

Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Magnetics	40.5	43.27	10.6	27.4	57.8
Middlings	31.3	77.40	5.28	37.9	22.3
Non-magnetics	28.2	78.62	5.24	34.7	19.9
Calculated head	100.0	63.92	7.42	100.0	100.0

Table 6 - Sala magnetic separation tests: pre-ground ore

Test No	Products	Feed Rate mm/sec	Intensity k gauss	Weight %	Analysis %		Distribution %	
					Insol	Fe_2O_3	Insol	Fe_2O_3
1.	Magnetics Non-magnetics Calculated head	108	21.4	88.9 11.1 100.0	54.5 85.5 57.9	8.51 4.28 8.04	83.6 16.4 100.0	94.1 5.9 100.0
2.	Magnetics Non-magnetics Calculated head	158	21.4	78.3 21.7 100.0	52.1 87.0 59.7	8.66 3.98 7.65	68.4 31.6 100.0	88.7 11.3 100.0
3.	Magnetics Non-magnetics Calculated head	158	13.8	73.1 26.9 100.0	48.7 86.7 58.9	9.10 3.99 7.73	60.4 39.6 100.0	86.1 13.9 100.0
4.	Magnetics Non-magnetics Calculated head	232	13.8	46.3 53.7 100.0	30.3 84.6 59.5	12.2 4.05 7.82	23.6 76.4 100.0	72.2 27.8 100.0
5.	Magnetics Non-magnetics Calculated head	341	13.8	36.1 63.9 100.0	19.1 81.9 59.2	14.60 4.38 8.07	11.6 88.4 100.0	65.3 34.7 100.0
6.	Magnetics Non-magnetics Calculated head	341	9.1	28.1 71.9 100.0	15.1 77.8 60.2	11.50 4.68 6.60	7.1 92.9 100.0	49.0 51.0 100.0

Table 7 - Talc concentrate leaching conditions

Test No	H_2SO_4 kg M^{-3}	HCl kg M^{-3}	Reducing agent g kg^{-1}	Temp °C	Pressure kpa	Time h
1a	3	-	-	25	100	240
2	-	327	$Na_2S_2O_4$(20)	95	100b	6
3	-	327	Na HSO_3(10)	95	100	6
4	618	-	Na HSO_3(10)	95	100	6
5	618	-	Na HSO_3(20)	95	100	6
6	177	-	-	110	637c	4
7	177	-	-	110	637	6
8d	177	-	-	110	637	4

a Bacteria source - thiobacillus ferroxidans
b 100 kpa corresponds to atmospheric pressure
c Includes an oxygen pressure of 426 kpa
d Surfactant added (1000 ppm)

Table 8 - Metal extraction relative % values

Test No	Analysis % Fe_2O_3	Metal extractions*			
		Fe_2O_3 %	Al_2O_3 %	MgO %	Weight Loss % wt
1	3.55	2.0	n.d.	n.d.	n.d.
2	3.55	13.4	83.2	8.8	5.2
3	3.36	18.6	92.6	13.5	9.7
4	3.57	16.6	97.6	12.0	7.5
5	3.55	25.7	93.6	19.6	17.0
6	3.33	27.3	n.d.	n.d.	31.8
7	3.55	20.6	n.d.	n.d.	10.5
8	2.77	49.8	n.d.	n.d.	24.5

*Relative percent metal extraction for Al_2O_3 and MgO are based on feed analyses of 0.39% Al_2O_3 and 28.6% MgO.
n.d. not determined.

Table 9 - Grinding and flotation parameter data: hammer mill product

Test No	Flotation Stage	Ground Size %-44µm	Feed Rate kg/h	Collector Conc g/t	No of Cells	Cell Volume L	Pulp Density % solids	Pulp Volume L	Retention Time min
10.	Feed	51.5	18.2	33.1	-	-	20.0	79.03	-
	Rougher		19.5	-	6	51.0	12.2	147.63	20.7
	Scavenger		1.6	4.7	3	25.5	2.9	28.3	28.3
	Cleaner #1		9.6	-	3	25.5	11.1	80.33	19.1
	Cleaner #2		13.0	-	3	25.5	6.8	181.74	8.4
	Cleaner #3		10.1	-	3	25.5	13.3	68.95	22.2
11.	Feed	48.0	18.2	47.3	-	-	20.0	79.03	-
	Rougher		19.9	-	6	51.0	9.8	189.3	16.2
	Scavenger		2.0	4.7	3	25.5	2.0	98.7	15.5
	Cleaner #1		10.9	-	3	25.5	11.1	90.9	16.8
	Cleaner #2		10.9	-	3	25.5	12.9	76.9	19.9
	Cleaner #3		9.1	-	3	25.5	14.3	59.0	25.9
12.	Feed	83.2	19.1	56.8	-	-	20.0	82.94	-
	Rougher		22.3	-	6	51.0	9.5	221.3	13.8
	Scavenger		3.9	4.7	3	25.5	2.8	135.9	11.3
	Cleaner #1		13.0	-	3	25.5	9.1	134.8	11.4
	Cleaner #2		11.1	-	3	25.5	11.0	93.5	16.4
	Cleaner #3		9.4	-	3	25.5	12.1	71.4	21.4
13.	Feed	68.3	18.6	61.5	-	-	20.0	80.8	-
	Rougher		20.7	-	6	51.0	9.0	215.9	14.2
	Scavenger		3.0	4.7	3	25.5	1.9	133.6	11.4
	Cleaner #1		12.3	-	3	25.5	10.4	109.4	14.0
	Cleaner #2		11.1	-	3	25.5	9.6	108.0	14.2
	Cleaner #3		10.3	-	3	25.5	14.7	63.4	24.1
14.	Feed	59.1	18.6	47.3	-	-	20.0	80.8	-
	Rougher		26.6	-	6	51.0	12.3	199.0	15.4
	Scavenger		9.5	4.7	3	25.5	7.0	135.6	11.3
	Cleaner #1		15.9	-	3	25.5	16.0	88.8	17.2
	Cleaner #2		16.4	-	3	25.5	10.8	140.7	10.9
	Cleaner #3		11.0	-	3	25.5	11.6	87.2	17.5

Table 9 Cont'd - Grinding and flotation parameter data: hammer mill product

Test No	Flotation Stage	Ground Size %-44µm	Feed Rate kg/h	Collector Conc g/t	No of Cells	Cell Volume L	Pulp Density % solids	Pulp Volume L	Retention Time min
15.	Feed	53.6	18.6	61.5	-	-	20.0	80.8	-
	Rougher		26.6	-	6	51.0	12.2	200.2	15.3
	Scavenger		22.5	7.1	3	25.5	9.8	214.9	7.1
	Cleaner #1		30.9	-	3	25.5	16.9	162.2	9.4
	Cleaner #2		20.7	-	3	25.5	16.3	113.8	13.4
	Cleaner #3		12.2	-	3	25.5	14.8	74.3	20.6
				-					
16.	Feed	58.7	18.6	71.0	-	-	20.0	80.8	-
	Rougher		24.0	-	6	51.0	9.4	240.3	12.7
	Scavenger		7.3	9.5	3	25.5	4.5	157.2	9.7
	Cleaner #1		17.0	-	3	25.5	11.5	136.5	11.2
	Cleaner #2		26.8	-	3	25.5	11.5	215.8	7.1
	Cleaner #3		18.4	-	3	25.5	15.6	105.9	14.4
				-					
17.	Feed	58.9	18.6	52.0	-	-	20.0	80.8	-
	Rougher		29.9	-	6	51.0	10.9	255.8	12.0
	Scavenger		17.6	7.1	3	25.5	10.3	159.8	9.6
	Cleaner #1		27.4	-	3	25.5	19.3	124.0	12.3
	Cleaner #2		28.4	-	3	25.5	18.0	138.8	11.0
	Cleaner #3		13.1	-	3	25.5	14.7	80.4	19.0
				-					
18.	Feed	57.8	18.6	61.5	-	-	20.0	80.8	-
	Rougher		27.3	-	6	51.0	10.6	237.9	12.9
	Scavenger		20.0	7.1	3	25.5	7.8	242.8	6.3
	Cleaner #1		22.4	-	3	25.5	15.7	128.4	11.9
	Cleaner #2		34.6	-	3	25.5	15.8	195.1	7.8
	Cleaner #3		19.4	-	3	25.5	15.6	111.8	13.7
				-					
19.	Feed	55.9	18.6	71.0	-	-	20.0	80.8	-
	Rougher		26.8	-	6	51.0	10.2	245.2	12.5
	Scavenger		12.3	9.5	3	25.5	7.3	160.4	9.5
	Cleaner #1		21.9	-	3	25.5	16.5	118.3	12.9
	Cleaner #2		39.3	-	3	25.5	16.7	208.9	7.3
	Cleaner #3		18.7	-	3	25.5	17.0	97.5	15.7

Table 10 - Product balances: hammer mill products

Pilot Run No 10 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	44.1	24.9	97.03	68.8
Cleaner tails #3	11.1	1.8	94.39	16.8
Cleaner feed #3	55.2	13.3	96.50	85.6
Cleaner conc #2	55.2	13.3	96.50	85.7
Cleaner tails #2	16.4	3.1	89.90	23.7
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	71.6	-	94.99	109.4
Cleaner conc #1	60.5	14.1	95.16	92.6
Cleaner tails #1	8.8	2.9	77.47	11.0
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	69.3	-	92.92	103.6
Scavenger conc	1.5	-	71.60	1.7
Scavenger tails	7.3	1.9	78.69	9.3
Scavenger feed (Cleaner tails #1)	8.8	2.9	77.47	11.0
Rougher conc	51.4	11.6	94.77	78.3
Rougher tails	55.9	7.3	34.65	31.1
Calculated feed (Feed + Scavenger tails)	107.3	-	63.40	109.5
Measured feed	100.0	18.5	62.19	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 11 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	49.0	26.9	96.94	75.9
Cleaner tails #3	1.0	1.6	93.36	1.5
Cleaner feed #3	50.0	14.3	96.87	77.3
Cleaner conc #2	50.0	14.3	96.87	77.3
Cleaner tails #2	9.7	3.0	89.70	13.9
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	59.7	-	95.70	91.2
Cleaner conc #1	58.7	14.7	95.76	89.8
Cleaner tails #1	11.0	2.0	82.14	14.4
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	69.7	-	93.60	104.2
Scavenger conc	1.9	-	97.60	3.0
Scavenger tails	9.2	1.5	78.98	11.6
Scavenger feed (Cleaner tails #1)	11.0	2.0	82.14	14.5
Rougher conc	58.1	11.7	93.85	87.1
Rougher tails	51.0	6.1	29.71	24.2
Calculated feed (Feed + Scavenger tails)	109.2	-	63.86	111.4
Measured feed	100.0	16.6	62.62	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 12 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	47.6	22.0	96.51	70.8
Cleaner tails #3	1.5	1.6	89.26	2.1
Cleaner feed #3	49.1	12.1	96.29	72.9
Cleaner conc #2	49.1	12.1	96.29	72.9
Cleaner tails #2	9.0	2.5	85.03	11.8
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	58.2	-	94.53	84.8
Cleaner conc #1	56.7	13.1	94.65	82.8
Cleaner tails #1	20.3	2.8	70.39	22.0
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	77.0	-	88.24	104.8
Scavenger conc	3.5	-	90.8	4.9
Scavenger tails	16.9	2.3	65.61	17.1
Scavenger feed (Cleaner tails #1)	20.3	2.8	70.39	22.0
Rougher conc	64.5	9.6	88.54	88.1
Rougher tails	52.4	7.3	36.04	29.1
Calculated feed (Feed + Scavenger tails)	116.9	-	64.95	117.2
Measured feed	100.0	17.1	64.84	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 13 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	52.0	25.0	93.55	75.6
Cleaner tails #3	3.5	1.5	88.17	4.8
Cleaner feed #3	55.5	14.7	93.21	80.4
Cleaner conc #2	55.5	14.7	93.21	80.5
Cleaner tails #2	3.9	2.1	85.47	5.2
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	59.5	-	92.70	85.7
Cleaner conc #1	56.0	14.5	93.04	81.0
Cleaner tails #1	13.8	1.9	75.94	16.3
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	69.8	-	89.65	97.3
Scavenger conc	2.8	1.7	89.60	3.9
Scaverger tails	11.0	1.5	73.15	12.5
Scavenger feed (Cleaner tails #1)	13.8	1.9	76.45	16.4
Rougher conc	63.1	13.6	89.29	87.6
Rougher tails	48.0	6.1	32.64	24.3
Calculated feed (Feed + Scavenger tails)	111.1	-	64.83	111.9
Measured feed	100.0	17.6	64.34	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 14 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	32.2	27.4	96.59	52.4
Cleaner tails #3	26.7	5.1	94.43	42.5
Cleaner feed #3	58.9	11.6	95.61	94.9
Cleaner conc #2	58.9	11.6	95.61	94.9
Cleaner tails #2	29.5	8.2	92.25	45.8
Cleaner feed #2 (Cleaner conc #1 + Clean tails #3)	88.4	-	94.49	140.7
Cleaner conc #1	61.6	21.2	94.52	98.1
Cleaner tails #1	53.5	7.0	89.55	80.7
Cleaner feed #1 (Rougher conc + Scavanger conc + Cleaner tails #2)	115.1	-	92.21	178.8
Scavenger conc	8.8	6.4	94.00	13.8
Scavenger tails	44.6	6.5	87.95	66.1
Scavenger feed (Cleaner tails #1)	53.4	7.0	88.80	79.9
Rougher conc	76.8	19.4	90.24	116.7
Rougher tails	67.8	7.0	41.70	47.6
Calculated feed (Feed + Scavanger tails)	144.6	-	67.48	164.3
Measured feed	100.0	17.2	59.37	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 15 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	45.2	29.3	94.77	71.6
Cleaner tails #3	20.3	7.0	93.38	31.7
Cleaner feed #3	65.5	14.8	94.34	103.3
Cleaner conc #2	65.5	14.8	94.34	103.2
Cleaner tails #2	45.9	10.6	88.47	67.9
Cleaner feed #2 (Cleaner conc 1 + Cleaner tails #3)	111.4	-	91.92	171.1
Cleaner conc #1	91.2	23.1	91.62	139.6
Cleaner tails #1	121.0	9.8	82.79	167.4
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	212.2	-	86.58	307.0
Scavenger conc	78.1	17.6	90.42	118.0
Scavenger tails	42.9	6.4	80.62	57.8
Scavenger feed (Cleaner tails #1)	121.0	9.8	86.95	175.8
Rougher conc	88.1	16.4	87.27	128.5
Rougher tails	54.8	5.0	31.01	28.4
Calculated feed (Feed + Scavenger tails)	142.9	-	65.70	156.9
Measured feed	100.0	17.3	59.85	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 16 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	52.1	27.8	92.53	80.1
Cleaner tails #3	46.9	6.5	89.47	69.7
Cleaner feed #3	99.0	15.6	91.08	149.8
Cleaner conc #2	99.0	15.6	91.08	149.8
Cleaner tails #2	45.3	8.6	81.87	61.6
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	144.2	-	88.25	211.4
Cleaner conc #1	97.3	21.7	87.50	141.4
Cleaner tails #1	39.2	4.5	67.87	44.2
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	136.5	-	81.87	185.6
Scavenger conc	10.3	7.6	80.89	13.8
Scavenger tails	28.9	3.3	64.42	30.9
Scavenger feed (Cleaner tails #1)	39.2	4.5	68.70	44.7
Rougher conc	80.9	12.3	82.25	110.5
Rougher tails	47.9	5.2	25.09	20.0
Calculated feed (Feed + Scavenger tails)	128.9	-	60.95	130.5
Measured feed	100.0	17.0	60.21	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 17 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	52.3	27.8	96.41	78.2
Cleaner tails #3	18.1	6.8	94.16	26.4
Cleaner feed #3	70.4		95.83	104.6
Cleaner conc #2	70.4	14.7	95.83	104.6
Cleaner tails #2	82.5	11.6	92.16	117.9
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	152.9	-	93.85	222.5
Cleaner conc #1	134.7	23.2	93.80	195.9
Cleaner tails #1	94.9	10.3	87.82	129.2
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	229.6	-	91.33	325.1
Scavenger conc	34.0	24.6	92.07	48.5
Scavenger tails	60.8	6.2	84.54	79.7
Scavenger feed (Cleaner tails #1)	94.8	10.3	87.24	128.2
Rougher conc	113.1	18.1	86.75	152.1
Rougher tails	47.7	6.5	29.60	21.9
Calculated feed (Feed + Scavenger tails)	160.8	-	69.78	174.0
Measured feed	100.0	20.1	64.50	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 18 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	56.9	28.4	90.97	81.9
Cleaner tails #3	47.6	8.6	87.30	65.7
Cleaner feed #3	104.5	15.6	89.30	147.6
Cleaner conc #2	104.5	15.6	89.30	147.6
Cleaner tails #2	81.5	12.0	85.49	110.2
Cleaner feed #2 (Cleaner conc #1 + Cleaner tails #3)	186.0	-	87.63	257.8
Cleaner conc #1	138.4	22.4	87.77	192.1
Cleaner tails #1	64.3	7.8	80.24	81.6
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	202.7		85.38	273.7
Scavenger conc	17.6	17.4	84.62	23.6
Scavenger tails	46.7	5.3	75.72	55.9
Scavenger feed (Cleaner tails #1)	64.3	7.8	78.15	79.5
Rougher conc	103.6	15.4	82.97	136.0
Rougher tails	43.1	6.4	26.53	18.1
Calculated feed (Feed + Scavenger tails)	146.7	-	66.40	154.1
Measured feed	100.0	20.3	63.22	100.0

Table 10 Cont'd - Product balances: hammer mill products

Pilot Run No 19 Products	Weight %	Pulp Density % solids	Analysis %	Distribution %
			Insol	Insol
Final concentrate	51.4	29.8	96.15	81.0
Cleaner tails #3	49.0	8.2	91.95	73.8
Cleaner feed #3	100.4	17.0	94.10	154.8
Cleaner conc #2	100.4	17.0	94.10	154.8
Cleaner tails #2	110.8	13.0	89.64	162.8
Cleaner feed #2 (Cleaner conc #1 + Clean tails #3)	211.2	-	91.76	317.6
Cleaner conc #1	162.2	24.4	91.66	243.7
Cleaner tails #1	66.2	7.3	79.11	85.8
Cleaner feed #1 (Rougher conc + Scavenger conc + Cleaner tails #2)	228.4	-	88.02	329.5
Scavenger conc	22.4	20.3	88.92	32.6
Scavenger tails	43.8	4.8	74.33	53.4
Scavenger feed (Cleaner tails #1)	66.2	7.3	79.26	86.0
Rougher conc	95.2	15.8	84.87	132.4
Rougher tails	48.6	6.6	23.91	19.0
Calculated feed (Feed + Scavenger tails)	143.8	-	64.26	151.4
Measured feed	100.0	21.0	61.02	100.0

Table 11 Sala - Magnetic separation test: hammer mill product

Products	Weight %	Analysis %		Distribution %	
		Insol	Fe_2O_3	Insol	Fe_2O_3
Magnetics	51.3	38.3	10.40	30.8	73.4
Non-magnetics	48.7	90.6	3.96	69.2	26.6
Head calculated	100.0	63.8	7.26	100.0	100.0